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FINAL TECHNICAL REPORT

A THEORETICAL INVESTIGATION OF POWER AND CONTROL CONFIGURATIONS FOR A HIGH G-ONSET CENTRIFUGE DRIVE SYSTEM

BY

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Human Centrifuge High G-Onset Rates Control

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An investigation of both the power drive system and the control system for high G-onset rates in a human centrifuge was carried out. Although the analysis was general, much of it specifically considered the A/F 37V-1 centrifuge at Brooks AFB. It is shown that an electric drive system, and gondola passenger control of G forces results in a system capable of simulating aerial combat maneuvers. The drive system consists of an SCR control of the A.C. line voltage applied to D.C. motors. The control system provides for cockpit stick control of the centrifuge's angular velocity and angular acceleration.

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b. RESEARCH OBJECTIVES

The purpose of the program was to investigate both the power and control configurations for a high G-onset rate centrifuge drive system. High G-onset rates as well as high G levels are necessary for realistic simulation of aerial combat maneuvers (ACMs) with the human centrifuge. Onset rate characteristics are limited by the drive systems. That is, the centrifuge drive system must be capable of supplying the necessary torque to achieve the angular acceleration and corresponding G-onset rates. In addition, for ACM simulation, the centrifuge passenger should be able to control his own G forces. Passenger control, via a control stick, of the power drive system is a purpose of the control system. An analysis of how the power drive system and the control system should operate and how they should operate together was the subject of the research.

c. STATUS OF RESEARCH EFFORT

For accurate ACM simulations, it is necessary to have both pilot control of the G forces and sufficient accelerating torque available from the drive system. Even though both of these characteristics are required, the investigation of each aspect was carried out relatively independently.

POWER

Present day technology favors all electric drive systems. Extremely accurate speed control of D.C. shunt motors from the A.C. line through SCRs in available. Metal rolling mill motors, for example, capable of withstanding two, three, or more times frequently repeated overloads can provide the required angular acceleration for high G-onset rates. Such drive motors can simulate ACMs.

The A/F 37V-1 centrifuge at Brookes AFB was considered as an example for much of the investigation.

An analysis of this centrifuge indicated that four 230 volt shunt motors, 110 horse power each with a 6X load factor could provide more than the necessary power for simulating ACMs. That is, they would provide 660 hp each for the short time necessary for six to eight G/sec onset rates from a G on G base of one. This is the $R\omega^2$ portion of the G forces on the gondola and does not include the tangenlial component due to $R\alpha$.

Figure 1 shows the physical arrangement.

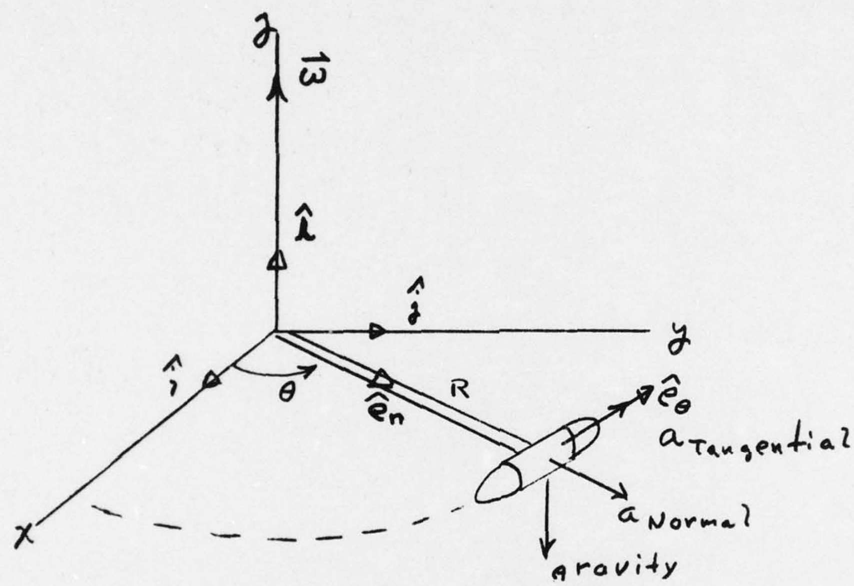


Figure 1. G forces acting on centrifuge's gondola.

Mathematically, the total G force can be expressed as:

$$\vec{G}_{total} = \vec{G}_{normal} + \vec{G}_{tangential} + \vec{G}_{gravity} \qquad (1)$$

substituting in appropriate quantities.

$$G_{total} = \frac{R}{g}\,\omega^2\,\hat{e}_n + \frac{R}{g}\,\alpha\,\hat{e}_\theta - \hat{k} \qquad (2)$$

where:

α = angular acceleration in rad/sec²

ω = angular velocity in rad/sec

R = radius arm in ft.

$\hat{i}, \hat{j}, \hat{k}, \hat{e}_n$, and $\hat{e}_\theta$ are unit vectors.

It is the G_{normal} which is of interest for ACM simulation, however for high G-onset rates α must be large. The power is given as:

$$\text{power} = j\ \alpha\ \omega\ \text{(ft-lb)/sec} \tag{3}$$

J is the moment of inertia about the rotational axis measured in lb.-ft.-sec^2.

Considering a G-onset rate of 4 G/sec, the average angular acceleration α would be:

$$\alpha_{avg} = \frac{R}{g}(\omega_4^2 - \omega_1^2) \tag{4}$$

where ω_4 = angular velocity required for $G_n = 4$

ω_1 = angular velocity required for $G_n = 1$

Combining equations 3 and 4, giving the peak power requirement:

$$\text{peak power} = \frac{JR}{g}(\omega_4^2 - \omega_1^2)\ \omega_4 \tag{5}$$

and

$$\text{peak hp} = \frac{JR}{500g}(\omega_4^2 - \omega_1^2)\ \omega_4 \tag{6}$$

An example calculation of the power requirements for a four G per second onset rate is as follows:

$$\text{hp} = \frac{JR}{500g}(\omega_4^2 - \omega_1^2)\ \omega_4$$

$$= \frac{67.3 \times 10^3 \times 20}{500 \times 32.2} \times (6.44 - 1.61) \times 2.54$$

$$\text{hp} = 1032$$

Numbers used are for the A/F 37V-1 centrifuge.

A simplified diagram showing the method of SCR speed control of D.C. motors is shown in Figure 2. For deceleration as well as acceleration control, additional circuitry can be included to provide for dynamic braking of the motor.

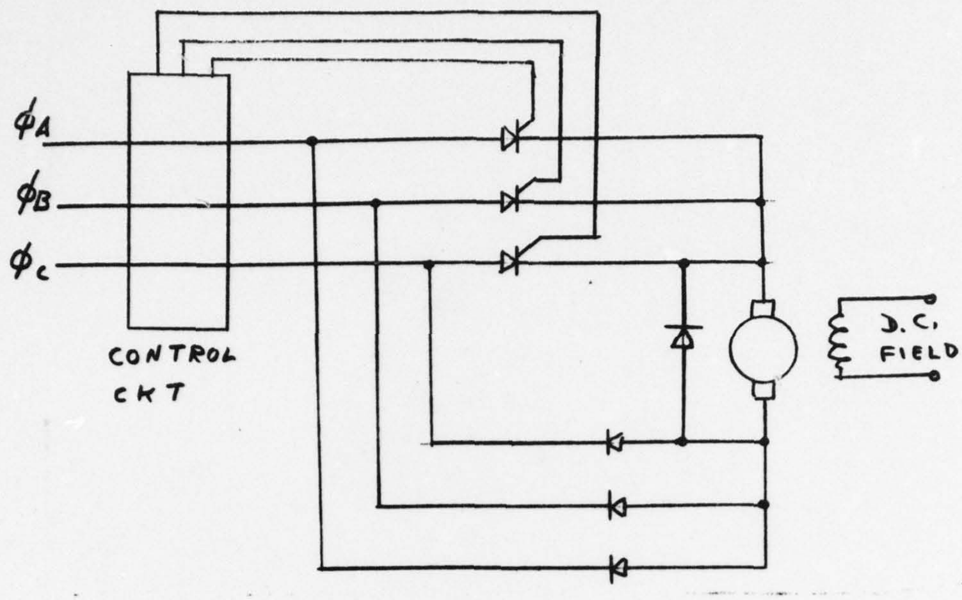


Figure 2. Simplified schematic of 34 A.C. power SCR speed control of D.C. motor

CONTROL SYSTEM

A system for achieving pilot control of his own G forces via a cockpit control stick was investigated. As part of the investigation an electronic control system was designed, and tested on the A/F 37V-1 centrifuge at Brooks AFB. The basic control circuit with modifications and additions has been incorporated into the A/F 37V-1 centrifuge system. This system is presently undergoing evaluation by personnel at the Biodynamics Branch at Brooks AFB for use in a pilot training program.

A schematic of the electronic system is shown in Figure 3, and photos of the system and its installation are shown in Figures 4, 5 and 6.

d. No technical publications have as yet been produced as a result of this work.

e. PROFESSIONAL PERSONNEL

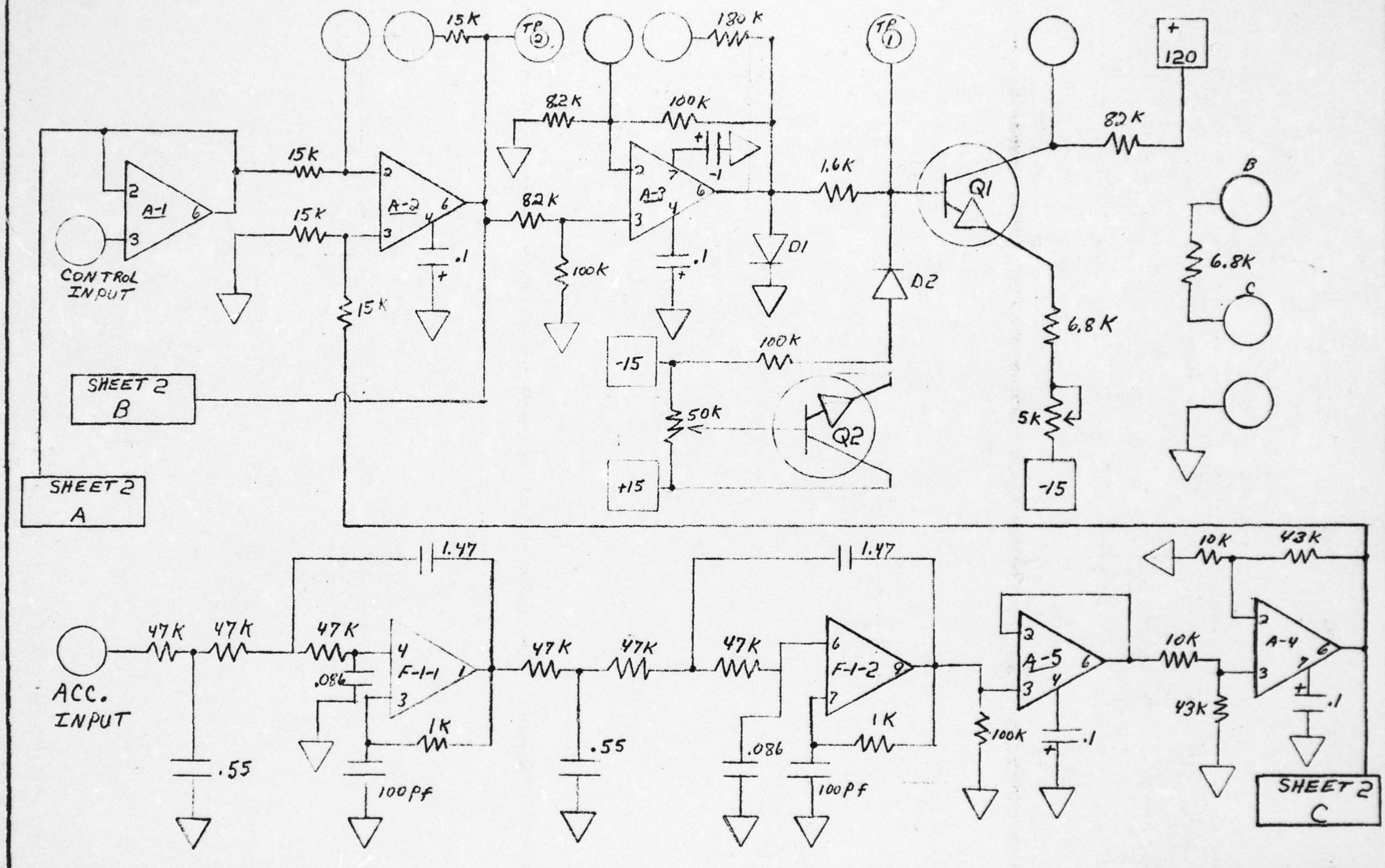
T. J. Jones, Project Director

Mike Bomba, Student Programmer

These two are Trinity University personnel. In addition, personnel from Technology, Inc. of San Antonio, Texas participated in portions of the project.

Technology Inc. is under contract to the Biodynamics Branch at Brooks AFB, and due to the nature of their work, their limited participation was appropriate. Mr. Roy Thompson, Technology Inc. BAFB manager, and certain of his crew made valuable contributions to the control system design and fabrication.

f. One specific area for additional investigation that became apparent was that of providing a more sophisticated display for the centrifuge passenger. A natural consideration for a more sophisticated display would involve computer graphics, and computer organized and controlled centrifuge experiments. In fact, it appears as if a microcomputer system could readily be incorporated into the centrifuge system to enhance its G simulation capabilities, monitor safety, control experiments, and analyze and organize experimental data. A real time computer control system should be a part of any modernization and updating program for a facility such as the A/F 37V-1 centrifuge. It is specifically recommended that a study of this be undertaken at an early date. A proposal to this effect is in preparation and will be submitted soon.



AUTOMATIC CONTROL SYSTEM

Figure 3-A

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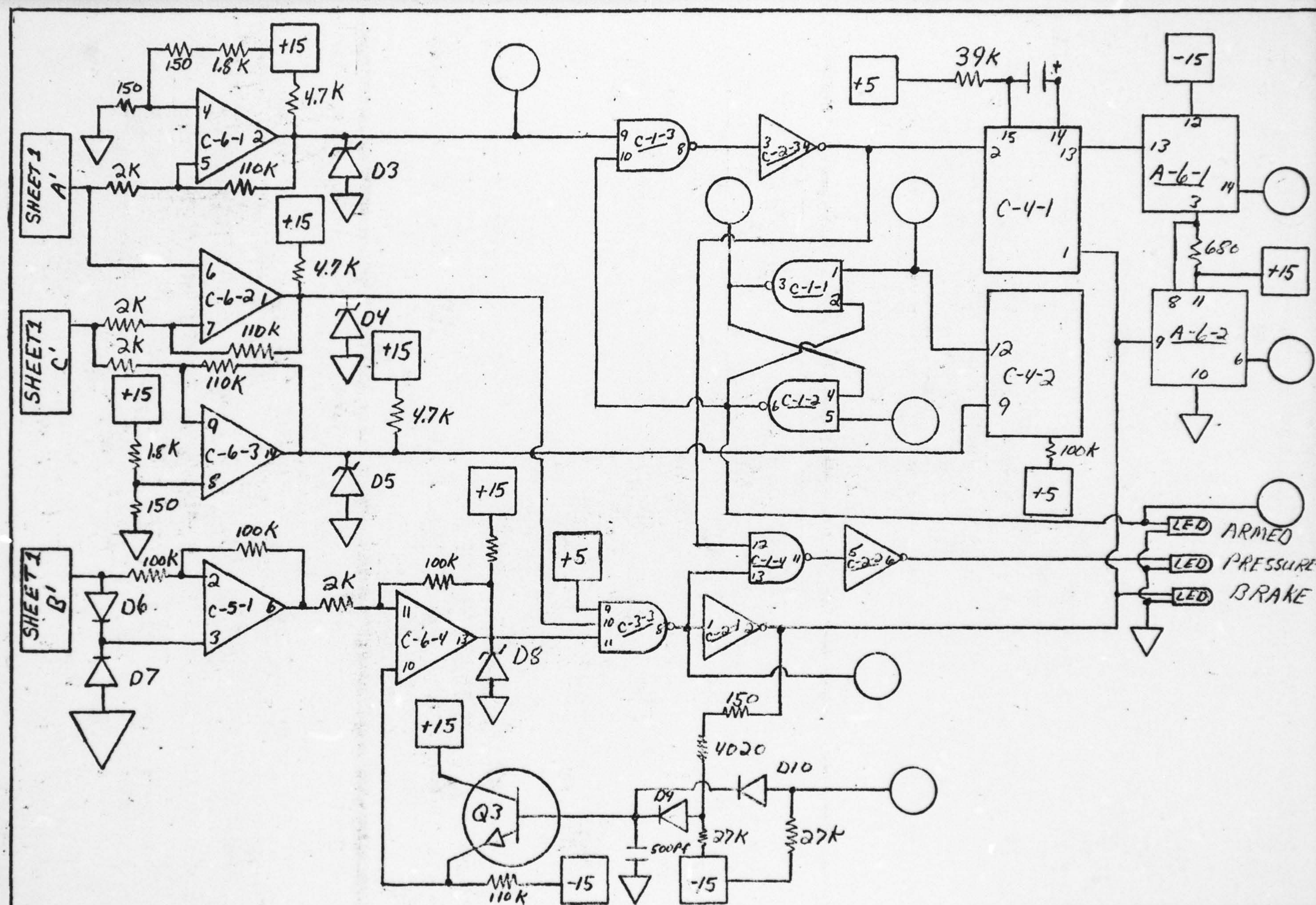

AUTOMATIC CONTROL SYSTEM

Figure 3-b

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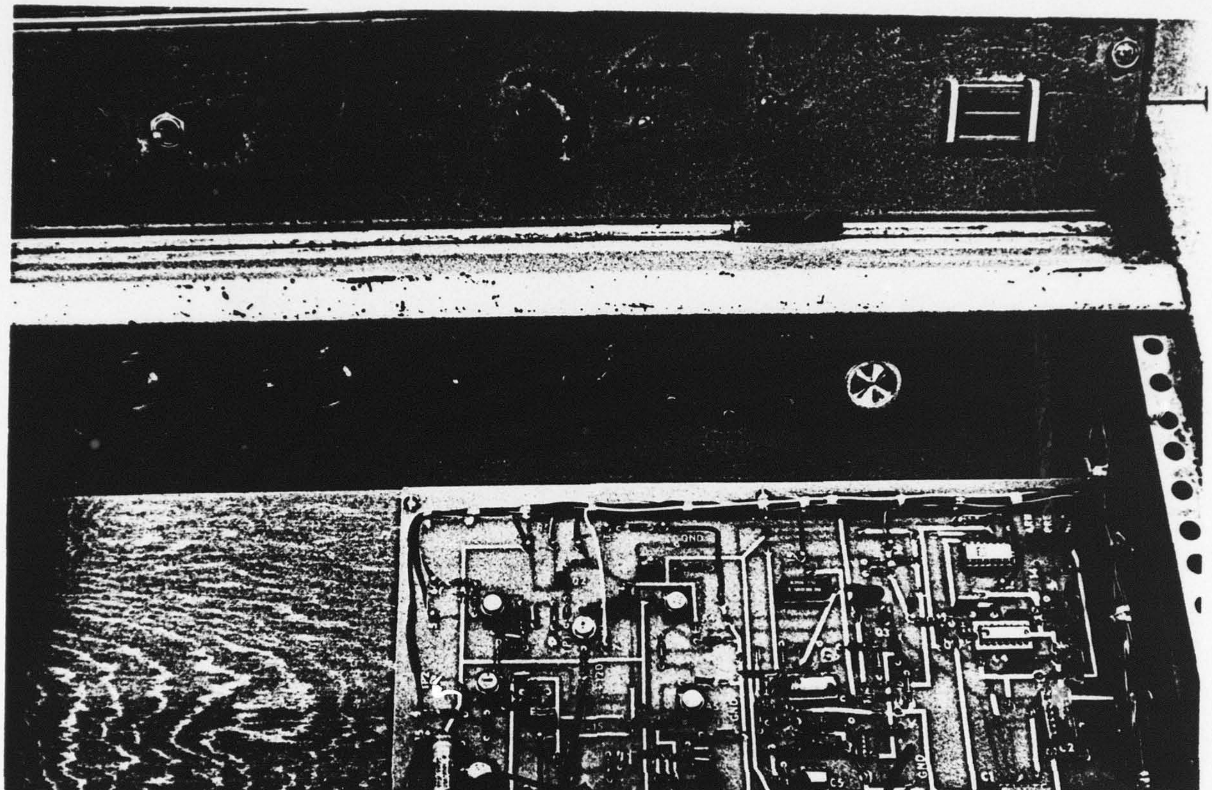

Figure 4

Control circuit as installed in A/F 37V-1 centrifuge
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Brooks AFB, TX.

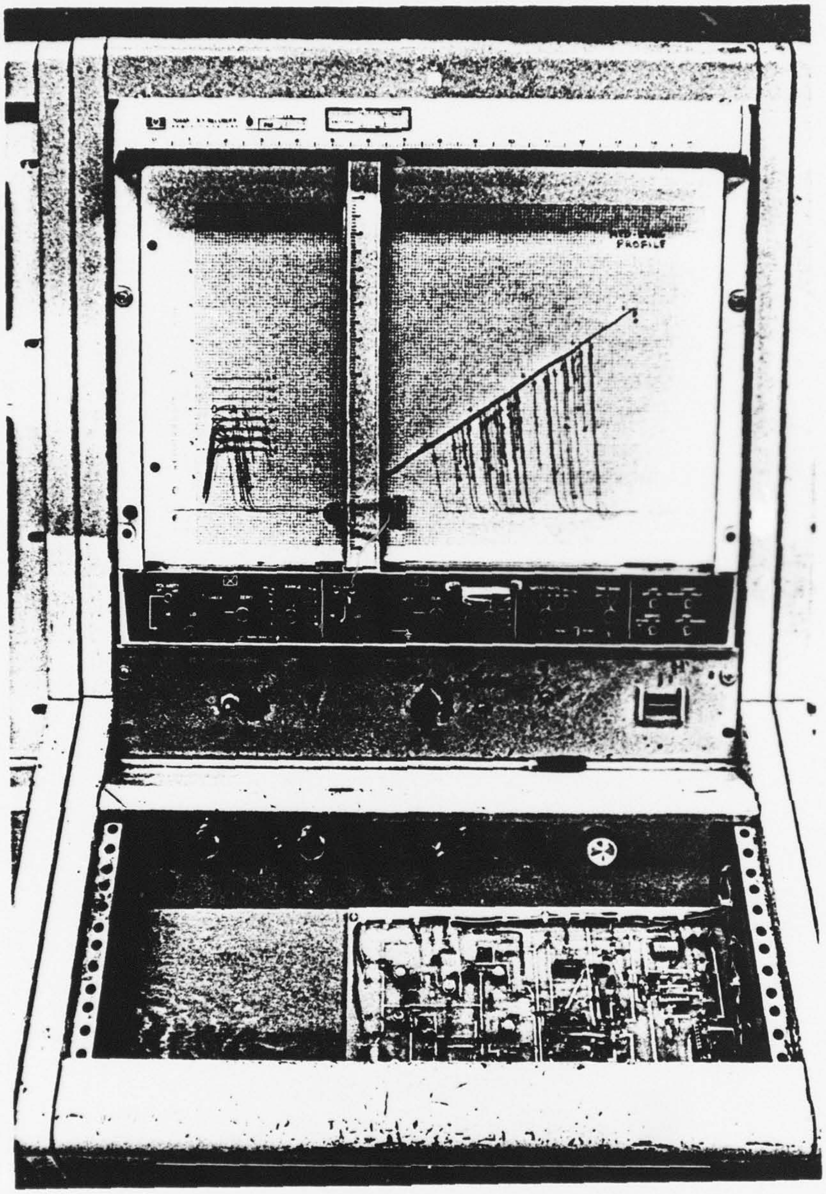

Figure 5

Another view of Control circuit on A/F 37V-1 centrifuge
at
Brooks AFB,TX.